AD 409 948

UNCLASSIFIED

FTD-TT- 63-353

TRANSLATION

STAINLESS SCALE-, ACID-, AND HEAT-RESISTANT STEELS AND ALLOYS

By

Yu. P. Davydov and G. V. Pokrovskiy

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

FTD-TT- 63-353/1+2+4

UNEDITED ROUGH DRAFT TRANSLATION

STAINLESS SCALE-, ACID-, AND HEAT-RESISTANT STEELS AND ALLOYS

By: Yu. P. Davydov and G. V. Pokrovskiy

English Pages: 17

Source: Russian Book, Listovaya Shtampovka Legirovannykh Staley i Splavov, Oborongiz, Moskva, 1962, pp. 58-72

T-66

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

FTD-TT-63-353/1+2+4 Date 15 May 19 63

P

STAINLESS SCALE-, ACID-, AND HEAT-RESISTANT STEELS AND ALLOYS*

All stainless scale-, acid-, and heat-resistant steels and alloys are conveniently divided into two groups according to properties exhibited in stamping and heat treatment.

A. Chrome steels which are strengthened by hardening and which lend themselves satisfactorily to stamping in the annealed state. This group includes the following sheet steels: Kh13 (Zh1), 2Kh13 (Zh2), 3Kh13 (Zh3), 4Kh13 (Zh4); Kh17N2 (EI 268); 10Kh12 NVMFA (EI962).

B. Chrome and chrome-nickel steels and alloys which are not strengthened by hardening and have high plasticity and lend themselves well to stamping in the hardened state.

This group includes the following sheet steels and alloys: 0Kh18N9 (EYa0); 1Kh18N9 (EYa1); 2Kh18N9 (EYa2); 1Kh18N9T (EYa1T); Kh13N4G9 (EI100); Kh23N18 (EI417); Kh24N25T (EI813); EI435; EI602; EI703; EI654; EI835; EI437B; EI696; EI696A; Kh15N9Yu; (SN-2; EI904);

---

* Yu. P. Davydov, Oeobennosti tekhnologii listovoy shtampovki zharoprochnykh i Titanovykh splavov, Sb. statey "Obrabotka zharoprochnykh splavov", Izd. AN SSSR, 1960.

Kh17N5M3 (SN-3; EI925) and others.

As is apparent from the data presented in Table 12, the steels and alloys under consideration have in the soft state a combination of mechanical properties favorable for stamping they have low yield points $\sigma_{0,2}$, a low ratio $\sigma_{0,2}/\sigma_b$, and high values of δ_{10}, δ_{eg} and ψ. This is mainly what determines the high stampability of these steels. Even after a cold working of up to 15-25% the sheets maintain their capacity for stamping to a considerable extent.

TABLE 12

Mechanical properties of sheets of stainless, scale-, acid-, and heat-resistant steels and alloys.

Material	State of material	σ_b	$\sigma_{0,2}$	$\frac{\sigma_{0,2}}{\sigma_b}$	δ_{10}	δ_{eq}	ψ
		kg/mm²			%		
Chrome steel	soft	40—80	18—45	0.5—0.6	15—35	8—18	45—65
Nickel and chromium nickel steels and alloys (excluding Kh15N9Yu and Kh17N5M3)	soft	60—90	25—45	0.45—0.48	36—65	20—35	50—75
	Cold worked by 15-25%	80—110	50—75	0.65—0.70	15—30	7—15	40—50
Kh15N9Yu and Kh17N5M3	soft	90—110	<40	0.25—0.35	25—35	16—20	45—65
	cold worked by 20-30%	110—138	70—80	0.55—0.65	10—20	6—12	25—40

The distinctive feature of stainless, scale-, acid-, and heat-resistant steels and alloys is their high strain hardening. Austenitic steels, which belong to group B, strain harden to a greater degree than ferritic steels, which belong to group A (Fig. 58).

The increased tendency to strain harden of these steels and alloys necessitates interoperation heat treatments to recover the plasticity of the cold worked material during complicated stamping procedures.

The high residual stresses occuring in parts stamped at a high degree of deformation cause cracks to form if the parts are not subjected to subsequent final heat treatment.

To relieve the residual stresses after stamping a lower temperature may be used in heat treatment than in hardening or full annealing: for austenitic steels and high-nickel alloys (group B), heating to $350-450^{\circ}$; for martensitic and ferritic (group A), $250-400^{\circ}$. Soaking at these temperatures is for 1-3 hours.

The softening (to obtain greater plasticity) heat treatment consists of annealing for chrome steels and hardening according to fixed schedules for austenitic steels. For steels Kh15N9Yu and Kh17N5M3, most softening is attained after normalizing from 1050°.

The sheet material intended for stamping should also be in the soft state. Sheet material, which has received additional cold working (Fig. 59) after hardening is used for stamping in individual cases.

The best grain size for the sheet material to ensure optimum stampability corresponds to No. 5-7 on the standard eight-number scale. It should be taken into account in stamping that the critical degree of deformation leading to grain growth after heat treating is 8-15%.

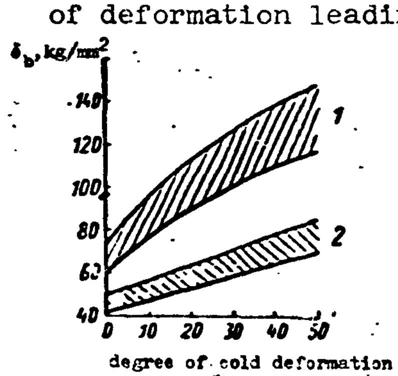

Fig. 58. Character of strain hardening in austenitic (1) and ferritic (2) stainless steels.

In comparison with nickel and chrome-nickel steels and alloys, chrome steels have less plasticity and lower stampability, which is nevertheless sufficient for the manufacture of complicated stamped sheet parts. The plasticity of these steels increases when they are heated to $550-600^{\circ}$ (Fig. 60). Such heating can be employed in individual cases to improve the stampability of the steels. In many cases heating ferritic steels to 90-150° makes possible a marked improvement in their stampability.

An interesting peculiarity is observed in the stamping of 18-8 steels. It happens that low heating of these steels (to 80-120°) improves their stampability appreciably. In order to explain this effect, we recall that 18-8 steels consist basically of the ternary system Fe-Cr-Ni and lie at the boundary between the pure austenite (γ) and austenite-ferrite ($\gamma+\alpha$) regions of the ternary system.

According to the phase diagram of Fe-Cr-Ni (Fig. 61), when these steels are heated to 950-1050° the austenitic structure is stable at these temperatures. Even slow cooling of the steel (e.g., in air) from these temperatures to room temperature proves sufficient to maintain the austenitic structure though, according to the phase diagram, for a nickel concentration of up to 12% the structure at room temperature should be austenite-ferrite ($\gamma+\alpha$).

Cold deformation of the steel makes the lattice of the γ solid solution unstable and brings about a $\gamma \rightarrow \alpha$ transformation. This transformation is due to the origin of high internal stresses during deformation and to strain hardening and loss of plasticity in the steel.

The phase diagram indicates that the stability of the austenitic structure will decrease as the nickel concentration in the steel decreases. Heating the deformed steel above a certain temperature, which depends on the relationship between the nickel and chromium concentration for a given amount of iron, will prevent the $\gamma \rightarrow \alpha$ transformation and maintain the austenitic structure.

This gives rise to a new method for deep drawing 18-8 stainless steel, which consists of heating the material to be stamped to 80-120°. This deep drawing method lessens strain hardening and residual stresses in the material and increases the limiting elongation coefficient to 2.3-2.4.

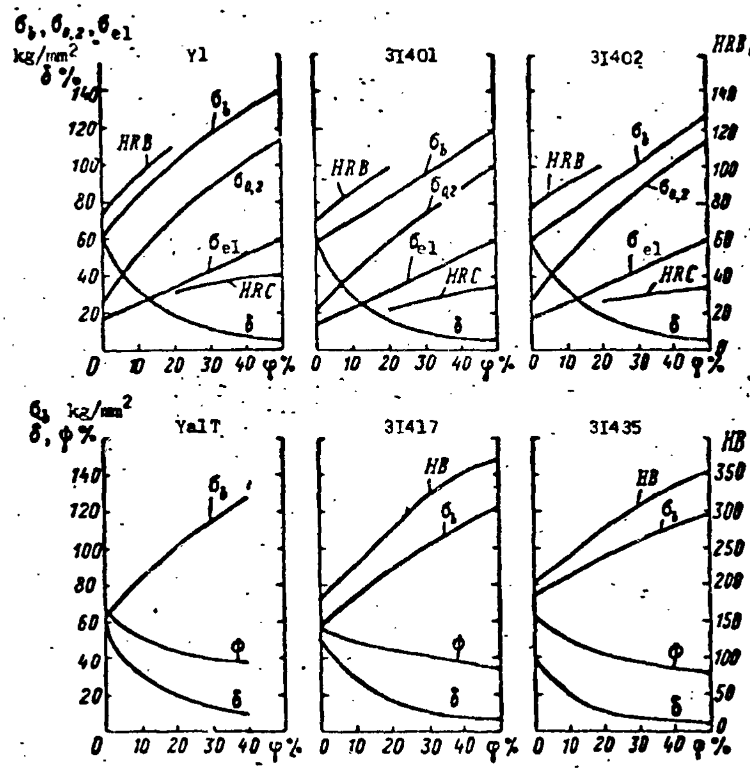

Fig. 59. The effect of cold hardening on the mechanical properties of stainless steels and heat resistant alloys.

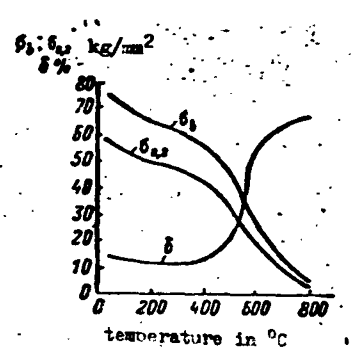

Fig. 60. Change in mechanical properties during heating of chrome steels (14% Cr).

No cases of cracks formation from residual stresses are observed on parts drawn upon heating to 100° from 1Kh18N9 (Yal) steel, 0.9 mm thick (Fig. 62).

The method of deforming austenitic stainless steels of type 18-8 at temperatures of 80-120° can obviously be applied to other forms of metal pressure treatment (e.g., rolling) in order to decrease strain hardening and residual stresses and to increase the plasticity of the material to be worked.

We should mention that when stainless steels are heated to higher temperatures (300-700°) no further improvement in plasticity (Table 13 and stampability occurs, and, therefore, as a rule, austenite steel forming even of intricately shaped parts is carried out at room temperature.

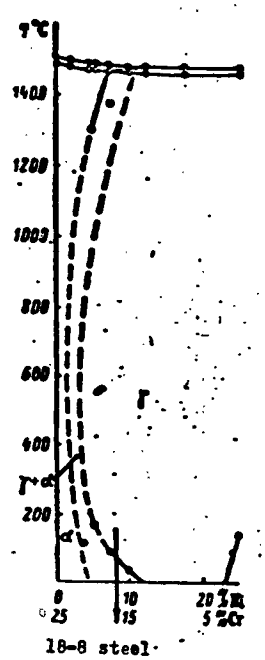

Fig. 61 Phase diagram of Fe-Cr-Ni system (cross section at 75% Fe).

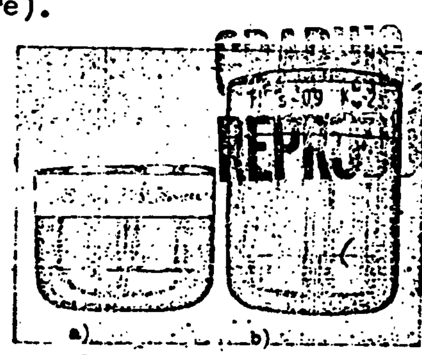

Fig. 62. General appearance of samples drawn from 18-8 steel. a) at room temperature ($K_{el.\ lim.}$ = 2.0-2.1); b) with heating to 120-150° ($K_{el.\ lim.}$ = = 2.3-2.4).

When stamping intricate parts, better results are ensured by deforming at low speeds, of the order of 0.15-0.25 m/sec, which is the operational rate of a hydraulic press. High pressing rates, since they increase resistance to deformation and impair the plastic properties of the material, lead to intense work hardening in the material and a decrease in the maximum degrees of deformation.

The basic data on the stampability of stainless, scale-, acid-, and heat-resistant steels and alloys (Table 14) indicate that steels and alloys may include materials with a very high capacity for bending, drawing, flanging and extrusion.

Chemical composition, along with such factors as quality of the rolled product, heat treatement and, structure, has considerable effect on the stampability of the materials under consideration.

TABLE 13

Variation in plasticity indices of some stainless steels with increase in temperature.

Brand of steel	Plasticity indices %	Testing temperature in °C						
		20	300	400	500	600	650	700
Ya1	δ	62	—	—	44	39	37	35
	ψ	70	—	—	40	58	44	36
EYa1T	δ	40,7	31,1	31,1	28,9	24,7	—	26,1
	ψ	63,2	65,0	65,0	64,7	61,2	—	58,7
EI40[illegible]	δ	46	—	—	45	—	44	—
	ψ	63	—	—	65	—	67	—

TABLE 14

Stampability of stainless scale-, acid-, and heat-resistant steels and alloys.

Material	Drawing		Flanging		Bending through 90°		Extrusion	
	K_{lim}	K_{op}	K_{lim}	K_{op}	r_{min}	r_{op}	flat K_{lim}	spherical K_{lim}
Chrome steel	1.8—2.0	1.6—1.75	1.5—1.7	1.3—1.5	1.0—2.0·S	2.0—3.0·S	0,22—0,30	0,40—0,55
Nickel and chrome-nickel steels and alloys	2.0—2,16	1.75—1.9	1.65—1.75	1.45—1.55	0.3—1,2·S	1.5—2,5·S	0,28—0,34	0.45—0,68

Experiments have shown that a change in the amount of certain elements, even within the tolerances of a given brand of steel or alloy, has a marked effect on stampability. For example, an increase in the nickel concentration of type 18-8 steels, by increasing the austenite stability, decreases the stain hardening capacity of these steels and increases their capacity for deep drawing. Thus it is desirable that the nickel concentration be as close as possible to the upper limit prescribed for these steels.

Type 18-8 steels which contain titanium (EYa1T) and niobium (EI402) have practically the same stampability as the steels Ya0, Ya1, and Ya2, which do not contain these additives. The content of molybdenum in type 18-8 steels (EI401) increases their stampability.

A systematic study of the alloys of Ni-Cr and Fe-Ni-Cr systems has made it possible to establish the effect of various alloying elements on the stampability of these alloys.

In particular, the negative effect of aluminum on the stampability of these alloys has been established (Table 15).

TABLE 15

The effect of aluminum concentration on the stampability of nickel-chromium alloys

Chemical composition in %				$K_{el.\ lim}$
Ni	C	Cr	Al	
base	0.1—0.15	19	3	1.87
"	0.1—0.15	19	4	1.58
"	0.1—0.15	24	3	1.87
"	0.1—0.15	24	4	1.20
"	0.1—0.15	24	5	1.20

This effect of aluminum carries over to other alloys (Ni-Cr-Nb; Fe-Ni-Cr; and others).

When iron is introduced into nickel alloys their stampability improves (Table 16).

This same table shows that an increase in the chromium concentration in chromium-nickel alloys (with and without iron) impairs their stampability. Slight additives of niobium and titanium into these alloys do not impair their stampability.

Tungsten in an amount of up to 4% and vanadium up to 1% do not alter the stampability of the alloys studied (the effect of large additives was not investigated).

Nickel and iron alloys increase their stampability somewhat when up to 2% of molybdenum is introduced into them.

Carbon affects the stampability of stainless and heat-resistant alloys noticeably only when its concentration is increased from 0.06-0.08% to 0.15-0.20%. After this same increase, however, Ni-Cr and Fe-Ni-Cr alloys remain very plastic.

When the concentration of Si in these alloys is raised to 1.25% their stampability remains high, but is only satisfactory at 1.4% Si.

The addition of small amounts of boron (about 0.005%) to some nickel alloys is not reflected in their stampability.

Heat resistant cobalt alloys possess high stampability.

One of the peculiarities of the plastic deformation of stainless scale-, acid-, and heat-resistant steels and alloys is high elastic recovery which necessitates carrying out labor consuming finishing and growing operations which require heat treating. The increased resistance of these steels to deformation requires considerably higher stamping loads than for carbon steels and nonferrous alloys.

The increased tendency to adhere to punch and die surfaces, the scratches on the surfaces of formed parts, and the increased wear of the punches and dies have until recently presented serious problems in the stamping of chromium-nickel steels. These problems have been solved by the development of highly effective lubricants and the use of special punch and die materials, which possess a high degree of hardness and create anti-friction conditions*.

---

* S. Ya. Sorokin; Yu. P. Davydov; I. I. Denker. Primeneniye zashchitnoy plenko dlya glubokoy vytyazhki nerzhaveyushchikh i zharoprochnykh staley i splavov, "Vestnik mashinostroyeniya", 1951, No. 7.

All these steels and alloys are capable of undergoing all types of sheet stamping. Some of the more important technological features of the individual operations involved in the forming of these materials should be mentioned.

Considerable stress is required for cutting, blanking, and punching. The value of the ratio $\frac{\sigma_{shear}}{\sigma_b}$ for chromium-nickel steels is 0.85-0.90, higher than for other sheet materials. This is explained by the high ductility of stainless steels and the necessity for the punch to pass almost completely through the sheet before the two parts of the blank separate. Usually the blanking stress for these steels is 20-40% higher than for low-carbon steels. In these operations an especially strict observance of the minimum clearances between the punch and die (not more than 3-7% of S on a side when $S \leq 3.0$ mm) and the ensurance of sharp edges of the cutting instrument (the maximum admissable blunting of the edges $\leq$ 0.25 mm) are required.

The minimum diameter of the punched hole for these materials is $d_h = 1.15\text{-}1.20 \cdot S$, but $\gg S$ for thick sheets. Viscous sulfonated oil is recommended as the lubricant for the blanking and punching operations. The speed in the parting operations should be decreased by 1/3 in comparison with the speed used in blanking and cutting carbon steels.

The optimal parameters for cutting on guillotine shears are: an increased angle of blade alignment of $5\text{-}12^{\circ}$, which ensures a smooth cut and moderate cold hardening of the shear edges; a cutting angle (blade taper) of 82-87%; a relief angle, needed to reduce the friction of the blade against the edge of the material being cut, of $2\text{-}3^{\circ}$; and a clearance between the blades of not more than 0.2 mm.

For the manufacture of the working parts of the blanking and punching presses as well as for the blades of the guillotine shears

U8A, U10A, Kh12M, and Kh12F1 steels with an HRC hardness after heat treating equal to 58-60 are used.

In addition to these kinds of stainless steel cutting, cutting on standard rollers and vibration cutters may be used.

As is known, chromuim-nickel alloys machine poorly. Because of this, the operations met with in processing plants involving chip removal from blanks and billets drill finishing, deburring; and edge filing cause a definite hardship, due to a decrease in the durability of the tool and the large consumption of labor. For this reason (the low durability of the milling cutter) the method of milling in fagots of curvilinear sheet blanks, which is widely used in finishing aluminum alloys, has not found industrial application.

Drawing operations occupy an important place in the manufacture of sheet parts from stainless, scale-, acid-, and heat-resistant steels and alloys.

High strains are allowable in the drawing operations owing to the high plasticity of the material. In single-operation drawing of austenitic steels the elongation coefficient is: $K_{el.\ lim} = 2.0\text{-}2.16$; $K_{el.\ op.} = 1.70\text{-}1.90$ ($\varphi = 40\text{-}45\%$). For chrome steels $K_{el.\ op.} = 1.55\text{-}1.75$ ($\varphi = 35\%$).

In multi-operation drawing the coefficient of the second and subsequent drawings depends on the value of the coefficient of the first drawing, and also on whether inter-operation heat treating is performed. The values of the limiting coefficients of the 2nd drawing are presented in Table 17.

Another technology must be adhered to in the multi-operation drawing of these steels and alloys from strip when the material is not receiving heat treated between operations. In this case the first drawing of austenitic steels and high-nickel alloys must be carried out with $K_1 = 1.45\text{-}1.55$ ($\varphi_1 = 30\text{-}35\%$); the second with $K_2 = 1.25\text{-}1.35$ ($\varphi_2 = 20\text{-}25\%$); the third with $K_1 = 1.20\text{-}1.25$ ($\varphi_3 = 15\text{-}20\%$); and the last with $K_k \leq 1.1\text{-}1.2$ ($\varphi_k = 10\text{-}15\%$). Following this, the drawn parts must be heat treated without delay since keeping them under stress for prolonged periods of time may lead to spontaneous cracking on the part of the material. In accordance with this, the values of K_1, K_2, K_3, ..., K_k for chrome steels must be appropriately reduced.

TABLE 16

Stampability of alloys of Ni-Cr-Al-Nb and Ni-Cr-Al-Nb-Fe systems

Chemical composition in %						$K_{dr.\ lim}$
Ni	C	Cr	Al	Fe	Nb	
Base	0.12	27	3	—	1.2	1.69
"	0.12	27	5	—	1.2	1.12
"	0.12	30	3	—	1.2	1.58
"	0.12	30	4	—	1.2	1.20
"	0.12	33	3	—	1.2	1.20
"	0.12	20	3	20	1.2	1.96
"	0.12	20	4	20	1.2	1.96
"	0.12	20	5	20	1.2	1.89
"	0.12	20	6	20	1.2	1.13
"	0.12	24	3	20	1.2	1.96
"	0.12	24	4	20	1.2	1.89
"	0.12	27	3	20	1.2	1.87
"	0.12	27	5	20	1.2	1.34
"	0.12	30	3	20	1.2	1.87
"	0.12	30	6	20	1.2	1.12
"	0.12	30	3	20	1.2	1.28

The values of the drawing stress needed for the calculation of the drawing load from the formula $P_{el} = ZS\sigma_{el}$ are given in the graph presented in Fig. 63.

The value of the specific clamping pressure in drawing austenitic steels and high-nickel alloys is given in Fig. 64.

In deep drawing the material being formed receives a considerable amount of strain hardening. The initial hardness of chromium-nickel steels and alloys increases as a result of drawing (with $K_1 = 2.0$) from an HRA of 45-60 to one of 65-75 in the maximum strain hardened zones of the drawn cup

TABLE 17

Material	Heat treating	$K_{el_1}=1.4$		$K_{el_1}=1.6$		$K_{el_1}=1.8$		$K_{el_1}=1.9$	
		$K_{dr_{lim2}}$	$K_{dr_{op2}}$	$K_{dr_{lim2}}$	$K_{dr_{op2}}$	$K_{dr_{lim2}}$	$K_{dr_{op2}}$	$K_{dr_{lim2}}$	$K_{dr_{op2}}$
chrome steels	without heat treating	1,30—1,40	1,20—1,25	1,25—1,35	1,15—1,20	—	—	—	—
	with inter-operation heat-treating	1,45—1,55	1,32—1,36	1,38—1,50	1,25—1,30	1,35—1,40	1,20—1,25	—	—
Nickel and chrome-nickel steels and alloys	without heat-treating	1,40—1,50	1,24—1,32	1,32—1,42	1,20—1,26	1,25—1,39	1,14—1,20	1,20—1,34	1,10—1,16
	with inter-operation heat-treating	1,54—1,62	1,40—1,45	1,45—1,59	1,34—1,40	1,40—1,50	1,26—1,31	1,36—1,44	1,23—1,28

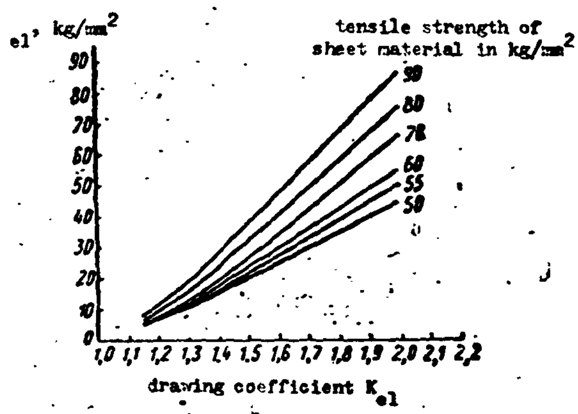

Fig. 63. Drawing stresses in stainless, scale-, acid-, and heat-resistant steels and alloys.

The thickness of the formed material undergoes a significant change on drawing, with a greater change in thickness the greater the deformation (Table 18).

The design factors of the drawing press radii of curvature of the working edges of the die r_d and punch r_p as well as the clearance between the die and punch z, have a considerable effect on the process of drawing stainless and heat resistant steels and alloys.

TABLE 18

Change in thickness of the material (in %) during deep drawing of stainless, scale-, acid-, and heat-resistant steels and alloys

Nature of thickness change	Elongation coefficient						
	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Thinning at the junction of the bottom with walls	3—4	4—5	5—6	6—8	8—10	10—12	13—18
Thickening of edge	12—16	16—20	20—23	23—25	25—27	27—29	29—32

On the basis of the research that has been done, it has been established that the optimal values of r_d, r_p, and z for forming these steels and alloys is greater than that adopted for carbon steels and nonferrous alloys. This is explained by the necessity of setting up maximum favorable conditions for the plastic flow of the metal during the drawing of these materials, since they differ by having an increased tendency toward strain hardening and require extremely high drawing loads. For frequently used material thicknesses (0.5-2 mm) the optimal value of r_{d1} is about 8-10 thicknesses of the material to be stamped. For subsequent drawings r_{dn} may be taken equal to (0.6-1.0) r_{d1}.

The radius of curvature of the working edges of the drawing punches should be

$$r_p = 0.5\text{-}1.0 \cdot S$$

The unilateral clearance between the punch and the die is determined from the formula

$z = 1.20\text{-}1.25 \cdot S.$

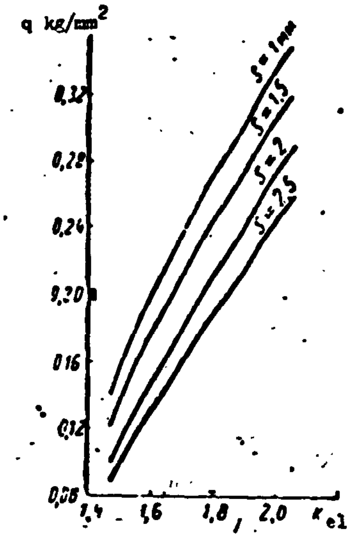

Fig. 64. Specific clamping pressures in drawing austenite stainless steels and high-nickel alloys.

The parts must not be dented or scratched in shipment since if this happens they will receive additional cold hardening, which may cause intensive grain growth during subsequent heating, and the scratches received will turn out to be points of stress concentration and premature breakdown in the part. Prolonged storage of the formed parts without heat treating should not be permitted, since keeping them under stress often leads to cracking of the material.

In conclusion we must mention a new method for deep drawing 18-8 steels (1Kh18N9 and 1KhN9T), which utilizes deep punch cooling.* The essence of this method consists in setting up favorable conditions for drawing by making use of a considerably large temperature head between the flange of the blank undergoing deformation (about 20°) and the shaped portion of the drawn cup on the punch (160-190°) and consolidating it by cooling the walls of the cup. Since the plasticity of the material in the undergoing deformation under the hold-down ring remains high, the degree of deformation in drawing can be increased considerably (up to $K_{el.\ lim.} = 2.7$). The production use of this method is complicated

---

* V. H. Revinov. Shtampovka-vytyazhka detaley iz zharoprochnykh listovykh metallov s primeneniyem glubokogo okhlazhdeniya, Sb. statey "Obrabotka zharoprochnykh splavov", Izd. AN SSSR, 1960.

by the need to use liquid nitrogen or air.

Bending of chromium-nickel steel and alloy parts, which is widely used in industry encounters no difficulties if we disregard the need to take into account the high elastic recovery of the material being deformed.

In all types of bending currently in use (in tool stamps, on universal and three-high mills, profiling on rollers, manual bending on mandrels, rubber-pad forming, and on trip hammers) the minimum and operational bending radii given in Table 14 must be taken into account.

In free V-bending and bending with calking of chrome-nickel steels and alloys the elastic recovery has the value shown in Table 19.

TABLE 19

Value of elastic recovery in V-bending through 90°.

Relative bending radius r/S	0.5	1	2	4	6	8	10	12
Value of $\Delta\varphi^{o}$ in free bending	3—4	4—5	5—6	6—7	7—9	8—10	9—12	10—15
Value of $\Delta\varphi^{o}$ in bending with calking	1	1—2	2—3	3—4	4—6	—	—	—

The flanging operations, usually performed in tool stamps on mechanical presses, also encounter no difficulties. The allowable strain for flanging stainless steel sheets is greater than for other sheet materials (aluminum and magnesium alloys, carbon and alloyed steels, etc.). High sides are successfully obtained in flanging with a radius of curvature of 3-4·S between the side and the flange. Because of their high relative elongation, these steels and alloys permit deep recesses (of the rigidity type) to be obtained by extrusion.

The steels under consideration permit parts to be manufactured from them by such widely used methods as forming on trip hammers, stretch forming, and rubber-pad forming on powerful hydraulic presses (at stepped up specific pressures in the pad retainer). When forming parts on spinning lathes, the feed of the tool needs to be mechanized. Deformation is carried out with the aid of a roller at low lathe shaft speeds (250-800 rpm).

Closely associated with the scale- and heat-resistant alloys examined above is chromium. The mechanical properties of chromium depend to a considerable extent on its purity. For refined electrolytic chromium at room temperature σ_b is about 25-30 kg/mm^2; $\sigma_{0.2}$, about 18-20 kg/mm^2; $\sigma = 2$-4%; $\psi = 2$-6%; and $E = 28{,}000$ kg/mm^2. In the ordinary state chromium sheets are extremely friable and are not capable of being formed. Even with relatively low heating, (about 400°) however, the sheets have a $\delta > 50\%$, which permits bending, drawing, flanging, and extrusion. At 800° the plasticity of chromium appreciably increases; the relative elongation of chromium at this temperature is 70-85%.

Sheet forming should be carried out at low deformation speed (on hydraulic presses).

Stress relief after plastic deformation takes place at 750°. Higher heating leads to recrystallization and intense grain growth thereby impairing the strength and plasticity.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE	Nr. Copies	MAJOR AIR COMMANDS	Nr. Copies
		AFSC	
		SCFDD	1
		DDC	25
		TDBTL	5
		TDBDP	5
HEADQUARTERS USAF		ASD (ASYIM)	2
		AEDC (AEY)	1
AFCIN-3D2	1		
ARL (ARB)	1		
OTHER AGENCIES			
CIA	1		
NSA	6		
DIA	9		
AID	2		
OTS	2		
AEC	2		
PWS	1		
NASA	1		
ARMY (FSTC)	3		
NAVY	3		
NAFEC	1		
PWS (B. Rawles)	1		
RAND	1		
AFCRL (CRXLR)	1		